# PATENT SPECIFICATION

DRAWINGS ATTACHED

**872,043**

*Date of Application and filing Complete Specification Dec. 18, 1957.*

*No. 39338/57.*

*Application made in United States of America on Jan. 17, 1957.*

*Complete Specification Published July 5, 1961.*

Index at acceptance:—Class 87(2), A1G(1:3X:5E:10), A2A2.

International Classification:—B29d.

COMPLETE SPECIFICATION

## Extrusion Apparatus

We, E. I. Du Pont de Nemours and Company, a Corporati- and compa-

## ERRATA

SPECIFICATION No. 872,043

Page 1, line 63, *for* " word " *read* " forward "
Page 3, line 67, *for* " gain " *read* " again "
Page 3, line 115, *for* " atached " *read* " attached "

THE PATENT OFFICE

*21st September, 1961*

... each have a groove cut out at a point near the inlet or feed hopper.

It has long been observed in the operation of devices for the plastication, mixing, and extrusion of thermoplastic resins that, with continuing operation, power requirements will periodically increase and output simultaneously decrease. One result of this periodic change in output is that the thermoplastic extrudate will vary in size and shape so that an unsatisfactory product will result. Eventually, particularly with hard thermoplastics such as nylon, there may sometimes result a complete jamming of the screw which necessitates a costly and time-consuming shut-down to clean the barrel and screw of the machine. Examination of such jammed screws has shown that pellets of the plastic have become caught, squeezed, and flattened between the flights of the screw and the cylindrical walls of the barrel. It is apparent that these jammed pellets caused increased friction and heating with the result that increased power was required to turn the screw. More careful examination has revealed that these pellets, as they softened and flattened, tended to stick to each other and to other pellets within the grooves of the screw, thus building up aggregates which would not move forward freely along the barrel. Such aggregates would act to restrict,

... of the screw. However, even with the use of such complicated devices, it has been found that many of the thermoplastic pellets become caught between the word edge of the hopper opening and the moving screw flight so that the problems of fluctuation of output and jamming of the screw have not been eliminated. Furthermore, these devices have the disadvantage of partially blocking the opening between the hopper and the transport screw, thus restricting seriously the maximum throughput of the machines.

An object of this invention is to provide an improved means of transporting pellets or chips of thermoplastic resins from a reservoir, such as a gravity-feed hopper, along a cylindrical barrel to the melting zone of the machine for continuously working, mixing, and extruding of the thermoplastic resin. Another object of this invention is to provide an improved screw which will deliver such thermoplastic resin pellets at a uniform rate from the hopper along the cylindrical barrel of a machine such as a plasticator or an extruder and which will eliminate the periodic decline throughput and increase in power requirements with time often encountered in the operation of such machines.

It is known to provide notches across the flight of extrusion screws for the purpose of allowing a back-flow of extruded material

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COMPLETE SPECIFICATION

## Extrusion Apparatus

We, E. I. DU PONT DE NEMOURS AND COMPANY, a Corporation organized and existing under the laws of the State of Delaware, United States of America, of Wilmington, State of Delaware, United States of America, (assignees of EVERT ARY JAN MOL), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an extrusion apparatus, suitable for processing thermoplastic resins. More particularly, it relates to an extrusion screw in which the flights of the transport section of the screw each have a groove cut out at a point near the inlet or feed hopper.

It has long been observed in the operation of devices for the plastication, mixing, and extrusion of thermoplastic resins that, with continuing operation, power requirements will periodically increase and output simultaneously decrease. One result of this periodic change in output is that the thermoplastic extrudate will vary in size and shape so that an unsatisfactory product will result. Eventually, particularly with hard thermoplastics such as nylon, there may sometimes result a complete jamming of the screw which necessitates a costly and time-consuming shut-down to clean the barrel and screw of the machine. Examination of such jammed screws has shown that pellets of the plastic have become caught, squeezed, and flattened between the flights of the screw and the cylindrical walls of the barrel. It is apparent that these jammed pellets caused increased friction and heating with the result that increased power was required to turn the screw. More careful examination has revealed that these pellets, as they softened and flattened, tended to stick to each other and to other pellets within the grooves of the screw, thus building up aggregates which would not move forward freely along the barrel. Such aggregates would act to restrict, and sometimes to prevent altogether the forward transport of the thermoplastic pellets toward the melting zone of the machine.

Various methods have been tried in the past to overcome the serious effect of this phenomenon. Thus in U.S. Patent 2,422,722 there is described a device for attachment to the forward edge of the hopper to provide a zone of varying cylindrical diameter in which some of the caught, squeezed pellets might become disengaged. In U. S. Patent 2,671,930 there is described a device for attachment to the wall of the hopper to provide a scraping action along the surfaces of the flights of the screw. However, even with the use of such complicated devices, it has been found that many of the thermoplastic pellets become caught between the word edge of the hopper opening and the moving screw flight so that the problems of fluctuation of output and jamming of the screw have not been eliminated. Furthermore, these devices have the disadvantage of partially blocking the opening between the hopper and the transport screw, thus restricting seriously the maximum throughput of the machines.

An object of this invention is to provide an improved means of transporting pellets or chips of thermoplastic resins from a reservoir, such as a gravity-feed hopper, along a cylindrical barrel to the melting zone of the machine for continuously working, mixing, and extruding of the thermoplastic resin. Another object of this invention is to provide an improved screw which will deliver such thermoplastic resin pellets at a uniform rate from the hopper along the cylindrical barrel of a machine such as a plasticator or an extruder and which will eliminate the periodic decline throughput and increase in power requirements with time often encountered in the operation of such machines.

It is known to provide notches across the flight of extrusion screws for the purpose of allowing a back-flow of extruded material

and that at least one of these notches is known to be located at the point where the flight meets the forward face of the inlet to the screw chamber.

According to the present invention there is provided an extrusion apparatus comprising a chamber having inlet and outlet means, a helical screw therein for propelling plastic material from the inlet to and through the outlet means, each flight of the screw being provided with a single groove across the ridge thereof, each groove being positioned at the point where each flight meets the forward face of the inlet to the screw chamber, each grooves being of width at most 15% of the circumference of the screw.

The helical screw may consist of a section for transporting and melting thermoplastic pellets and a section for working and compressing the plastic and forcing it through a screen pack and die.

When reference is made to "each flight" in this specification and the appended claims, the situation of a screw having only one flight is included.

Figure 1 is a cross-section view taken on the axis of a screw which shows the transport section of a screw in place inside a barrel with a groove cut out of the flight at the intersection of said flight with the vertical projection of the forward edge of the hopper.

Figure 2a is a plan view along axis of the screw illustrating a flight having a notch with its sides cut parallel to the axis of the screw.

Figure 2b is a plan view of the screw illustrating a flight having a groove with its sides cut perpendicular to the axis of the screw.

Figure 2c is a plan view of a groove similar to that of Figures 2a and 2b except that the sides are cut at an acute angle to the axis of the screw.

Figures 2d, 2e, and 2f are fragmentary cross-sectional views of a portion of the flight showing several possible configurations of the grooves of Figures 2a, 2b, and 2c.

Figure 3a is a plan view along axis of screw in which a semi-elliptical groove is cut from the flight.

Figure 3b is a cross-sectional view of the screw in which a semi-elliptical groove corresponding to that in Figure 3a is cut from the flight.

Figure 4 is a cross-sectional view similar to Figure 1 except that the transport section has more than one flight with a groove cut from each flight where that flight meets the juncture of the forward edge of the hopper and the barrel.

Although this is not essential to the embodiment of this invention, the preferred material of construction of the screw is an alloy steel, a stainless steel or a cold-rolled steel.

In Figure 1, at the point (1) where the screw flight (2) of the feeding section of the screw (3) contacts the meeting-point (4) of the cylindrical barrel (5) and the forward edge of the hopper (6) a small groove is cut out of the screw flight. The size of this groove is sufficiently large to allow an unmelted thermoplastic pellet to pass back therethrough. In the preferred embodiment of this invention, this groove will be from 100%—300% as wide and deep as the maximum dimension of the pellet. However, where the outside diameter of the flight is large, as compared with the size of the thermoplastic pellets, said groove should not be greater than 15% of the circumference of the screw-flight, and preferably it should be 2% to 6% of this circumference. The depth of the groove will generally be limited to the depth of the screw flight but may be less than this where the depth of flight is greater than the maximum dimension of said thermoplastic pellets. The shape of the groove is not critical since any generally concave shape is satisfactory. The sides of the notch may be parallel, perpendicular, or at an acute angle with respect to the axis of the screw as illustrated in Figures 2a, 2b and 2c; the perpendicular art illustrated in Figure 2b is preferred. Equally well the cross section of the groove may be semi-elliptical, as illustrated in Figures 3a and 3b, provided that the minimum depth of the semi-ellipse is at least as great at the maximum dimension of the thermoplastic pellets which it is desired to transport with the screw; generally U-shaped notches will function equally well. The maximum diameter (7) of the screw, pitch (8) of the screw flights, flight width (9), depth (10) of the screw flights, and total length of the screw are immaterial to the embodiment and operations of this invention. However, the clearance between the outside diameter of the flights of the screw and the barrel walls generally must be from 0.001 inch to 0.003 inch per inch of barrel diameter, and the helix angle of the flights of the transport section should be between 10° and 30°. Furthermore, the screw may have a single start, as illustrated in Figure 1, or it may have two or more starts as illustrated in Figure 4. Where the screw is constructed of multiple starts, a similar groove is cut in the flight of each start where that screw-flight will contact the point (4) of Figure 4.

It is possible to employ this invention in various types of machines for plasticating, working, and extruding the thermoplastic resin into various shapes, forms, and articles of commerce. The construction of the screw beyond the transport region will depend upon the operation which is to be performed upon the thermoplastic resin. Generally there will be a melting zone where the thermoplastic is converted into a fluid either by heat supplied through the walls of the cylindrical barrel, or by heat generated by mechanical working of the thermoplastic resin, or by a combination of both means. Beyond the melting zone there

may be an extrusion zone where the compacted fluid resin is forced, by the action of the screw, through various screen packs and dies to form filaments, rods, tubes, sheets, or wire coverings as desired.

This invention is further described and explained in the following examples which serve to illustrate specific embodiments and operation of the invention:—

## EXAMPLE 1.

In one particular embodiment of this invention, a transport screw 30 inches long was constructed of an alloy steel. The extruder was similar to that shown in Figure 1, the maximum diameter of the screw (7) being 1.991 inches, and the cylindrical barrel being 2.000 inches in diameter. The flight pitch (8) was 2 inches, giving a helix angle (12) of 17.7°, the flight width (9) was 0.200 inches, the depth of flight (10) was 0.250 inches, and the root diameter (11) was 1.491 inches. At the point (1) where the screw flight, with the screw in operating position within the cylindrical barrel would contact the point (4), a groove 0.250 inch wide and 0.250 inch deep was cut out of the screw flight. The bottom of the groove was cut concentrically with the root of the screw and the sides of the groove were cut perpendicular to the axis of the screw, resulting in a groove shown in Figure 2b and 2d.

Said screw, constructed as described hereinabove, was inserted in a 30-inch long cylindrical barrel (5) and fastened in place by means of a coupling at (13) to a variable speed drive.

This screw was started rotating at 40 revolutions per minute. The hopper was charged with commercial nylon resin pellets having a parallelepiped shape; the size of these pellets was 0.125 by 0.125 by 0.250 inches. This assembly was operated without application of heat and with no die on the end of the barrel so that throughput could be determined by collecting the solid nylon pellets at the exit end of the cylindrical barrel. The output of this screw under these conditions averaged 6.5 grams per revolution, varying between 5.0 and 7.5 grams per revolution. It was observed that no nylon pellets were caught between the forward edge of the hopper opening and the moving screw flight. A few pellets were temporarily trapped at the side edge of the hopper opening but moved forward over the flight into the cut-out notch and were released at this point. Thus no build-up of jammed, aggregated, particles occurred, there was no heat buildup, and power requirements and throughput remained quite constant.

By way of comparison and contrast, a screw constructed according to identical specifications but without the feature which defines this invention, that is, without a groove cut from the screw flight, was installed in the same cylindrical barrel and operated in the same manner, employing the same type of nylon pellets. In this case, the initial delivery rate gain was about 6.5 grams per revolution. However, at the end of five minutes' operating time, the output had fallen to less than 1.0 grams per revolution and the power requirements to turn the screw had substantially increased. As operation was continued, sudden increases in output occurred periodically, followed by similar declines until the machine finally was almost jammed. The jammed machine was dismantled, and it was found that numerous pellets of nylon were squeezed and flattened between the screw-flight and the barrel. Several aggregates of flattened pellets were found which could have effectively blocked transport of the nylon pellets along the barrel.

## EXAMPLE 2.

In another particular embodiment of this invention, an extrusion screw 36 inches long was constructed of alloy steel. The diameter of the screw was again 1.991 inches, and the first 30 inches from the rear toward the front (exit end) of the screw was constructed exactly as described for the transport screw of Example 1 including the point of invention, a groove 0.250 inches wide and 0.250 inches deep cut from the flight at the point (1) of Figure 1 with the same configuration as the notch described in Example 1. In the final 6 inches of the screw the depth of flight was decreased from 0.250 inches to 0.060 inches, the decrease being made in a uniform manner over one turn of the flight. The flight pitch was maintained at 2 inches.

This screw was inserted in a 40-inch long cylindrical barrel with an internal diameter of 2.000 inches; it was fastened in place by means of a coupling to a variable speed drive at the rear. The barrel was provided with means for heating it electrically along its full length. Means were provided for circulating chilled water to cool the neck of the hopper where it entered the heated cylindrical barrel. At the forward end of the barrel, means were provided for attaching, interchangeably, dies for forming the extruded thermoplastic resins into various shapes and forms.

In the first experiment with the machine described above, a die for forming the extruded resin into a $\frac{5}{8}$ diameter inch rod was atached to the end of the extrusion barrel, together with appropriate screen packs. The screw was started turning at 50 revolutions per minute, and the hopper was charged with the commercial nylon resin described in Example 1. The extruded rod of nylon was quenched in a water bath at it came from the die, and was then transported at a constant rate by means of passage through pinch rolls to a cutter where it was cut into standard lengths. The rate of extrusion remained constant over the periods of operation (four hours or longer) and the diameter of the extruded rod never varied by more

than 4% from the average value, $\frac{5}{8}$ inch.

By way of comparison and contrast, an extrusion screw identical with the above but lacking the point of invention, that is, without a groove cut in the flight, was operated in the same barrel under identical conditions with the same type of nylon thermoplastic resin. The extrusion rate rapidly fell to about 80% of that obtained with the use of the screw embodying the disclosed invention. The diameter of the extruded rod obtained with this screw varied by about $\pm 20\%$ from the average during each minute of operation. During an extended extrusion run with this screw, the screw nearly jammed on two occasions; at these times, the extruded rod dwindled to a mere filament or broke entirely.

Analogous, comparative results were obtained with the two screws described above when, instead of a rod die, a die for the production of tubes or a die for coating wire with the nylon resin was employed. It was found that the improved uniformity of output by means of this invention was of particularly great value in obtaining uniform coating of the resin on wire.

EXAMPLE 3.

In another specific embodiment of this invention, a larger screw was constructed for extruding thermoplastic resins. The transport section of said screw was 40 inches long. As illustrated in Figure 4, the maximum diameter (22) of said screw was 3.992 inches for use in a cylindrical barrel having a 4.000 inch inside diameter. Said transport section of said screw was constructed with two flights, (16) and (17). The flight pitch (23) of the aforesaid leads was 5 inches, giving a helix angle (27) of 21.7°. The flight width (24) was made 0.400 inches and the flight depth, (25) 0.861 inches. The root diameter, (26) was 2.270 inches. At the point (14) and (15) where said screw flights, with said barrel in operating position within the aforesaid cylindrical barrel, would normally contact the projection of point (19) of the forward edge (21) of the hopper-opening, semi-elliptical grooves 0.600 inches wide and 0.250 inches deep, at the minor radius of the ellipse, were cut out of said screw flights, as illustrated in Figures 3a and 3b, which shows a perspective view and a cross-sectional view, respectively, of the aforesaid groove as cut from one flight of the screw. The sides of the groove were cut at about 45° to the axis of the screw as indicated in Figure 2c.

Beyond the transport section of the screw, the depth of flight of the screw was decreased to 0.200 inches, the decrease being made in a uniform manner over on turn of the flights (5 inches). The flight pitch was maintained at 5 inches for the remainder of the length of the screw (15 inches). The total flighted length of the screw was 60 inches.

The overall length of the screw described was 6 feet, including butt (29) and point. This screw was placed in a cylindrical barrel of equal length having an internal diameter of 4.000 inches. Said screw was fastened by means of bolts at point (28) to a variable speed drive mechanism. Means were provided to heat the entire length of the barrel electrically by use of three separately controlled, cylindrical band heaters. Means were provided to cool the hopper where it entered the cylindrical barrel to prevent softening and sticking of the resin in the hopper. At the forward end of the barrel, means were provided for attachment of screen packs and of any one of a number of interchangeable extrusion dies.

In one particular experiment employing this screw, a standard pipe die for the extrusion of thermoplastic pipe of one inch outside diameter and 0.125 inch wall thickness was bolted to the end of the assembly described hereinabove. The aforesaid screw was operated at 45 revolutions per minute. The hopper of this extrusion apparatus was charged with the commercial nylon resin described in Example 1, and sufficient heat was supplied through the walls of the barrel to melt the nylon resin by the time it reached the section of the screw having the shallower depth of flight. Nylon pipe extruded in this experiment was quenched in cold water and drawn through the quench bath at a constant rate by means of a pinch roll designed for grasping pipe. Production rate remained constant over extended periods of operation. Examination of the nylon pipe which was produced showed that it had a very uniform diameter and wall thickness. The uniformity of this pipe reflected the exceptional uniformity of throughput obtained with this screw.

The above examples are illustrative only, and are not intended as limiting the scope of this invention. Thus it should be obvious that anyone skilled in the art could construct screws with many variations in detail without going beyond the scope and intent of this invention. Obviously the length and the diameter of the screw can be varied over a wide range, the number of starts and the pitch and depth of the flights of the transport section can be varied, and, in combination with the transport section, there can be incorporated any construction suited to the operations to be performed upon the resin. Furthermore, it is obvious that the point of invention is the construction of a groove in each flight of the transport section of the screw at the place where it will coincide with the points (4) or (19) of Figures 1 and 4, respectively. The size of the groove is limited only as disclosed hereinabove. The shape of the groove is not particularly important, being generally concave as illustrated in Figures 2a, 2b, 2c, 2d, 2e, 2f, 3a, and 3b. The shape could equally well be a

U shape, provided only that dimensions of width and depth fall within the ranges hereinabove disclosed.

As hereinabove described, this invention completely eliminates the trapping of pellets, in the transport sections of extrusion screws, between the flights of the screws and the walls of the cylindrical barrels. Extrusions of thermoplastic resins carried out with said screws can be continued for unlimited periods of time without heat build-up, without major fluctuation in power requirements, and without fluctuation in transport rate of the plastic pellets with resultant fluctuation in extrusion rate and accompanying fluctuation in the size and shape of the extruded filament, rod, bar, tube, wire covering, or sheet. A further advantage of this invention is that it can be embodied in a simple modification of existing machines with the result that expensive replacements or expensive and complicated modifications of existing machines, which may reduce the capacity of the machines without eliminating the problem, need not be made.

WHAT WE CLAIM IS:—

1. An extrusion apparatus comprising a chamber having inlet and outlet means, a helical screw therein for propelling plastic material from the inlet to and through the outlet means, each flight of the screw being provided with a single groove across the ridge thereof, each groove being positioned at the point where each flight meets the forward face of the inlet to the screw chamber, each groove being of width at most 15% of the circumference of the screw.

2. An apparatus as claimed in Claim 1 in which the helical screw consists of a section for transporting and melting thermoplastic pellets and a section for working and compressing the plastic and forcing it through a screen pack and die.

3. An apparatus as claimed in Claim 2 in which there is only one groove in the transport section of the screw.

4. An apparatus as claimed in any of Claims 1 to 3 in which the width of each groove is between 2% and 6% of the circumference of the screw.

5. An apparatus as claimed in any of Claims 1 to 4 in which each groove is semi-elliptical in cross-section.

6. An apparatus as claimed in any of Claims 1 to 5 in which each groove is U-shaped in cross-section.

7. An apparatus as claimed in any of Claims 1 to 6 in which the sides of each groove are perpendicular to the axis of the screw.

8. An apparatus as claimed in any of Claims 1 to 7 in which the clearance between the outside diameter of the flights of the screw and the chamber walls is from 0.001 to 0.003 inches per inch of chamber diameter.

9. An apparatus as claimed in any of Claims 2 to 8 in which the helix angle of the flights of the transporting section of the screw is from 10° to 30°.

10. An apparatus as claimed in any of Claims 1 to 9 in which the screw is constructed of multiple starts, similar grooves being cut in the flight of each start where the screw flight meets the forward face of the inlet to the screw chamber.

11. An apparatus as claimed in any of Claims 1 to 10 in which there is heating means to heat the chamber containing the screw.

12. An apparatus as claimed in Claim 11 in which there is an extrusion zone beyond the heating zone.

13. An apparatus as claimed in Claim 12 in which the extrusion zone contains a die for the production of tubes or a die for coating wire with the thermoplastic material.

14. An extrusion apparatus according to Claim 1 and substantially as hereinbefore described.

15. An extrusion apparatus according to Claim 1 substantially as described in any of the foregoing examples and as illustrated in any of the accompanying figures.

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Chartered Patent Agents.

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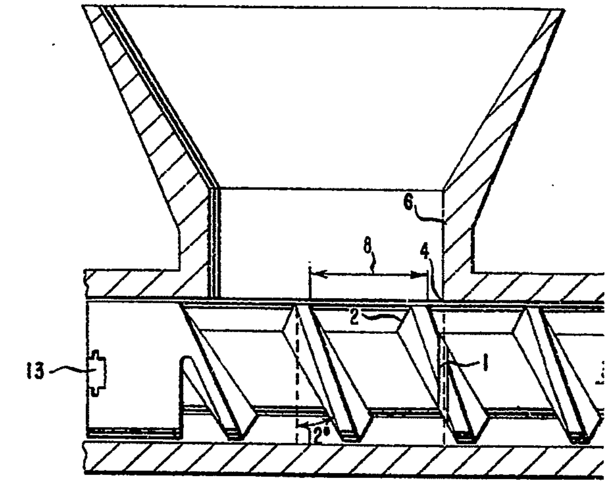


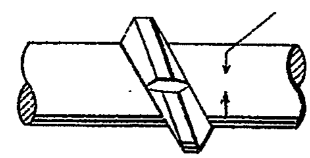



Fig. 2a

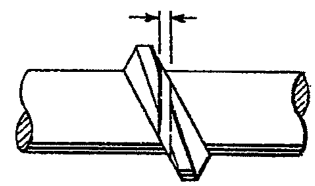


Fig. 2b

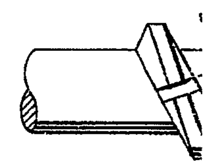


Fig.

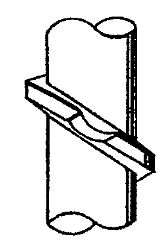


Fig. 3a

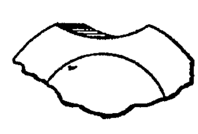
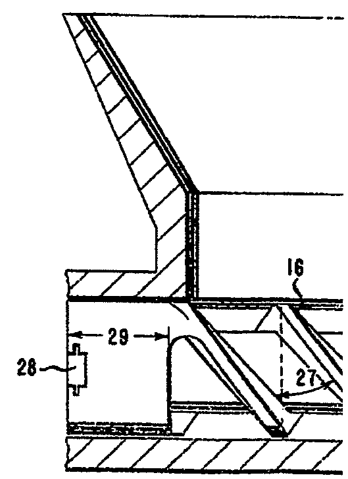


Fig. 3b



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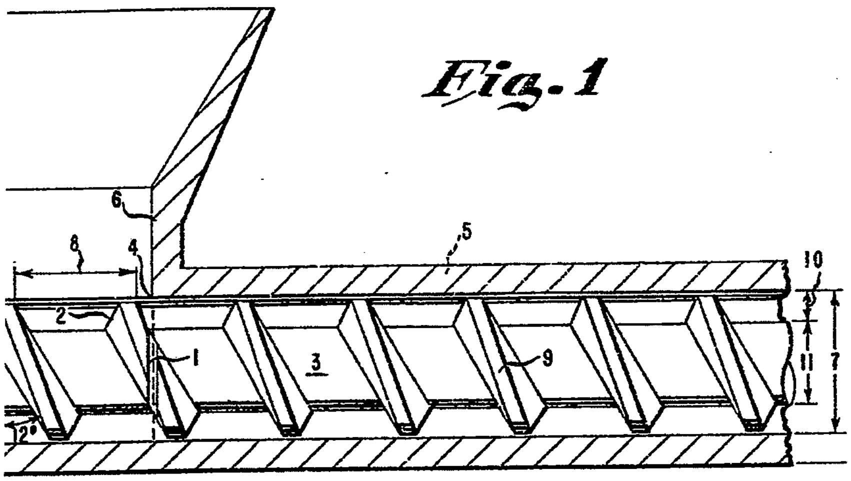


Fig. 1

b

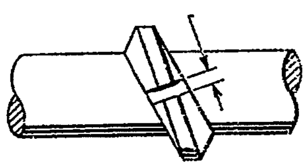

Fig. 2c

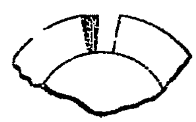

Fig. 2d

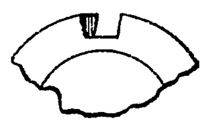

Fig. 2e

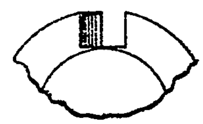

Fig. 2f

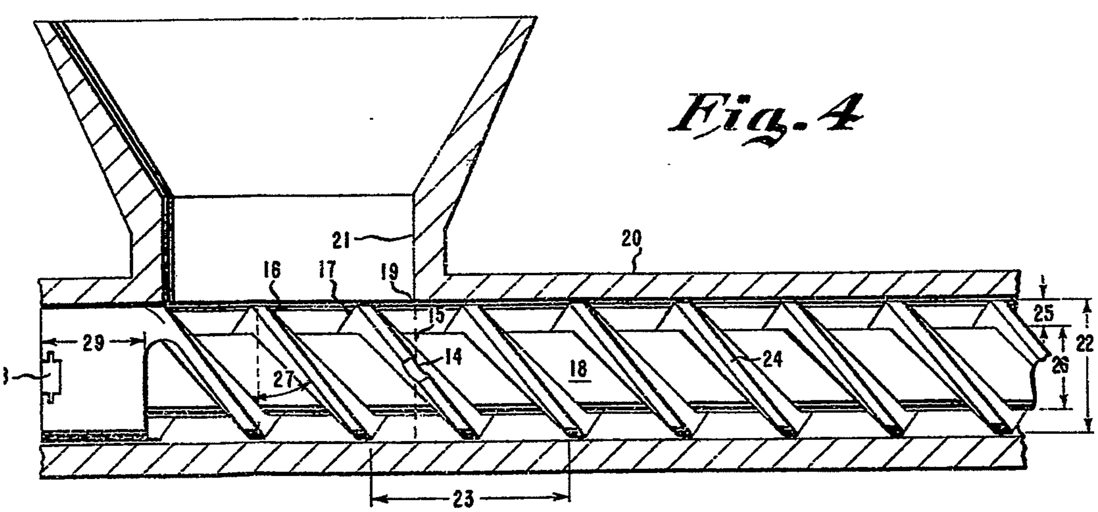


Fig. 4

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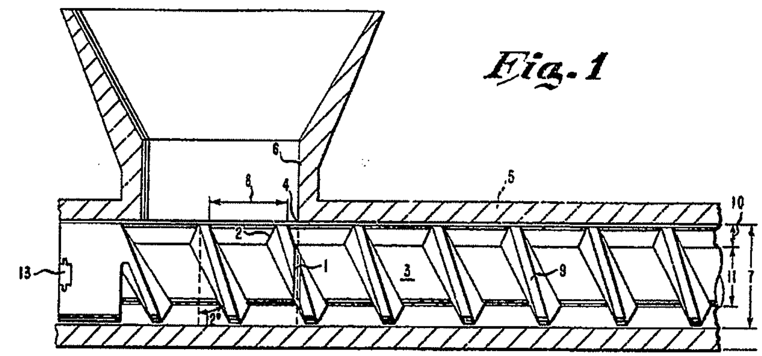


Fig. 1

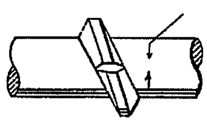

Fig. 2a

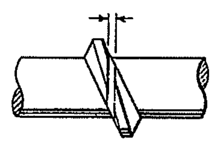

Fig. 2b

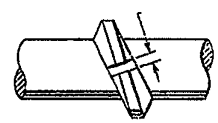

Fig. 2c

Fig. 2d

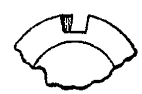

Fig. 2e

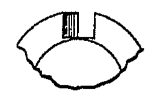

Fig. 2f

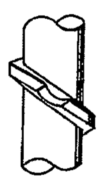

Fig. 3a

Fig. 3b

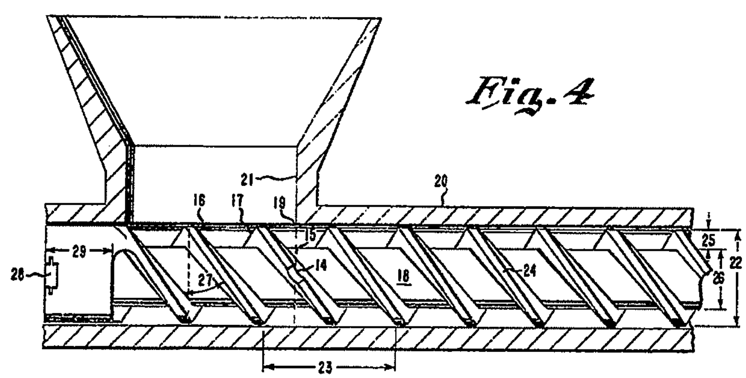


Fig. 4